SOME ROOF-CONTROL PRACTICES IN COAL MINES OF THE UNITED KINGDOM

BY JOHN W. BUCH AND ANDREW ALLAN, JR.

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by

John W. Buch[1/] and Andrew Allan, Jr.[2/]

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INTRODUCTION

Safety and cost in mining coal beds under the extreme pressures found at depth, full extraction to conserve resources, and even surface subsidence to minimize damage of improved areas have directed much well-deserved attention, in the United Kingdom, to roof-control methods. Because the effects of pressure will be felt intensely as our Pennsylvania anthracite mines grow deeper, the senior author took advantage of an opportunity afforded by a mission to Europe[3] to observe, to a limited extent, the effects of pressures found in deep mines and the manner in which they are controlled.

Organized research relating to strata control has been carried on in Great Britain for nearly 25 years. These activities have been ably outlined by Dr. D. W. Phillips.[4] Physical properties of coal-measure rocks, movements of roof and floor, and types of face and roadway supports have been investigated. Some of the forces induced by the extraction of coal have been measured. The results of this research have been publicized and openly discussed, and much progress has been made in establishing a better factual understanding of roof-control problems and their solution.

ACKNOWLEDGMENTS

The author wishes to acknowledge the friendly cooperation of H. M. Chief Inspector of Mines in arranging an itinerary and of H. M. Inspectors of Mines of the several inspection districts visited. The opportunities to discuss roof control and other problems with British mining engineers, managers, and agents were most helpful and enlightening, and likewise are gratefully acknowledged.

SYSTEMS OF MINING COAL[5]

Room-and-Pillar

Fundamentally, the room-and-pillar system involves driving a series of narrow parallel headings, which are connected by cross headings, to form pillars for partial or complete subsequent extraction. This system has been applied without difficult to shallow beds. In deeper beds, the slow rate of advance in solid mining and of pillar extraction often resulted in excessive crush over the workings, low percentage of recovery, and increased dead-work costs.

3/ Member, Solid Fuels Mission to the Europeen Theater of Operations, June-September, 1945, organized by the Technical Industrial Intelligence Committee of the Joint Chiefs of Staff.

4/ Phillips, D. W., Research on Strata Control in Great Britain: A.I.M.E. Tech. Pub. 2062 (Coal Technology) November 1946.

5/ Reid, C. C., Chairman to the Minister of Fuel and Power, Coal Mining Report of the Technical Advisory Committee: London, March 1945.

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Longwall Advancing

In the longwall-advancing system, a panel of coal is extracted by advancing the face on a broad front. Roadways for ventilation and transportation are supported by rock packs in and/or at the edges of the mined-out areas. In addition, packs are built to support the general mass of strata and to control the roof near the working face.6/ Such packs allow gradual settlement of the massive overlying strata and tend to reduce periodic intensive fracturing and minimize bumps. Where these forces are out of control, accidents from falls may result. Spontaneous heating and conditions favorable to the initiation of explosions also may result from excessive strata movements.7/ Subsidence is even over the working area, and the rate and amount can be regulated within limits by the method and quality of stowing or packing.5/

An example of strip packing, which is the method of packing most commonly employed in the advancing-longwall system, is shown in figure 1. Bed thickness is 5 feet; overburden is 2,275 feet. Material for the stone packs is taken from the wastes, which cave as the face advances. If the roof material does not cave readily, it must be drilled and blasted to supply this material. Support at the working face is achieved with props, either wood or steel, and chocks (wood). These face supports are reclaimed and moved forward with successive cuts. Uniform quality of packs is essential for proper control of weight, which is further accomplished, accurately, by varying the number and width of packs. The first ripping, or mining of rock sufficient for roadway height, is done at the face end of the packs; a second ripping is carried on about 300 feet behind the face, in this example, to establish final roadway height after the mined-out area has subsided.

In normal conditions, where face conveyors are used, the economic length of face has been found to be 100 to 150 yards for single units and twice that length for double units.5/

Longwall advancing is the principal system of mining in 74 percent of the collieries in Great Britain. It is believed that this percentage can be reduced in favor of room-and-pillar mining where depths of beds and geological conditions will permit.5/

Longwall Retreating

In this system headings are driven, in coal, to form large pillars, which are then extracted by working back toward the roadway from which the headings were started. The system has not been adopted on any appreciable scale, but in the comparatively small number of cases in which the system has been used, excellent results in concentration of production and high output per

---

6/ The Problems of Accidents from Falls of Ground. Part II, Supports: British Ministry of Fuel and Power, Safety in Mines Research Board, Sheffield, England, 1937.

7/ Humphrys, H. J., H. M. Divisional Inspector of Mines, Report on the Causes of and Circumstances Attending the Upheaval of Floor which Occurred on the 24th April, 1942, at the Barnborough Mine Colliery, South Yorkshire.

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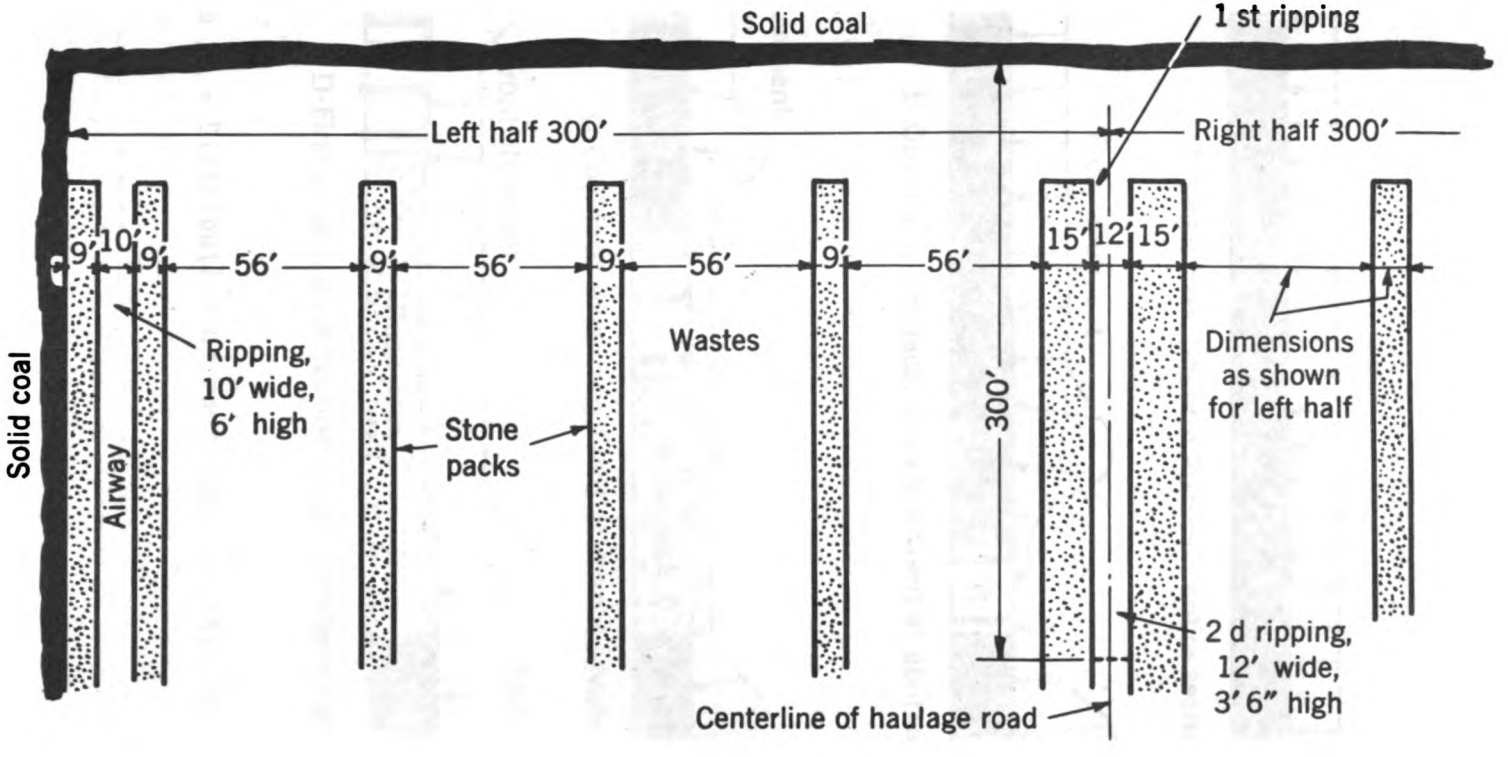

Figure 1. - Strip packing, advancing longwall.

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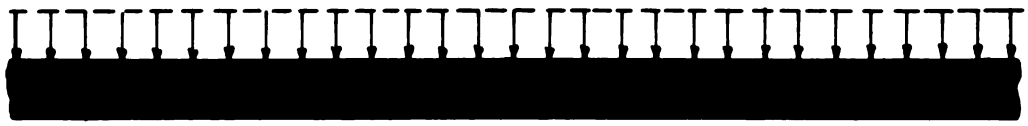
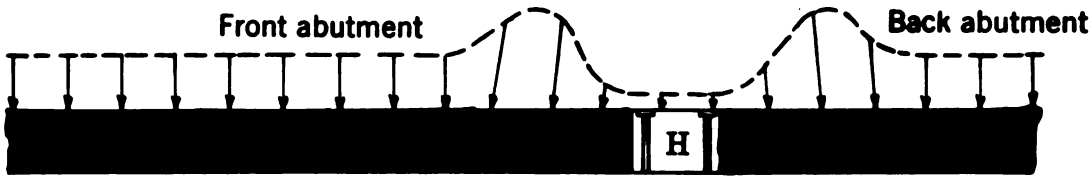
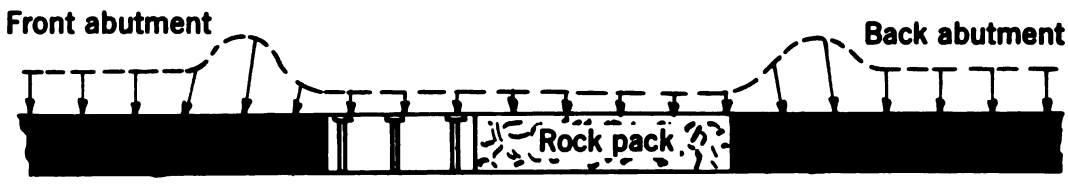


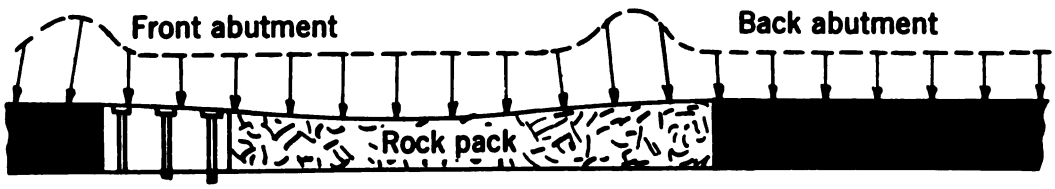
A-Virgin coal: Uniform load over entire seam



B-Opening a new face: Load increased at abutments



C-Coal face advancing: Front abutment advancing



D-First weight: Back abutment load transferred to pack

Figure 2. - Distribution of roof load in vicinity of a coal face.

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man per shift have been attained. There are, however, many instances in which roof pressure or floor heave precludes driving narrow headings into the beds. Wide headings, with rock-pack supports, have been used with success where strata pressures were not too severe. Conditions have been noted in which roof weight cannot be controlled on the retreat without resorting to much the same system of support as in longwall advancing in order to obtain safe face working conditions and prevent crushing of the headings outby.5/

ROOF LOADS AND FORCES INDUCED BY MINING

Compression tests have shown that rocks are able to bear the loads of overlying material, without lateral constraint, at depths greater than present mining.8/ In mining, equilibrium is destroyed, and the resulting action of the weight of the overlying strata is superimposed on the coal bed, with or without the enormous lateral or tangential stresses due to structural or tectonic folds; and thrusts, if uncontrolled, may be extremely hazardous and may add immeasurably to the cost of mining as well.

Front and Back Abutments

Experiments have shown that the load on the roof in the vicinity of the coal face does not increase with the depth from the surface, a more important factor than depth being the nature of the rocks for some distance above and below the bed.9/ This is true because there is an arching effect at right angles to the face, which results in concentration of load along two lines approximately parallel to the coal face, one of which is some distance in advance of the face over the solid coal and the other over the gob some distance behind the face. These two zones of increased pressure are termed the "front and back abutments," and they move forward as the face advances.

For example, in figure 2, section A shows a uniform roof load over a coal bed before mining. In section B, a new face has been opened by driving heading H. The original roof support has thus been removed at H, and the load from over H is now carried by the coal ribs. The points of increased pressure, as previously noted, are termed "front and back abutments." In section C, a longwall face has advanced to the left for some distance, but not far enough to outspan the solid coal supports for the arch. In section D, the face advance has exceeded the distance over which the roof will arch and span from solid coal ribs. Hence, a break occurs in strata immediately above the bed, and the back-abutment pressure shifts to the rock pack.

Movement and pressure measurements that serve to prove the foregoing abutment theory have been determined accurately.10/11/ Abutment loads are 2,000 to 3,000 pounds per square inch for 1,000-foot depth and 4,500 pounds per square inch for 2,000-foot depth. Increases and decreases of load pressures were accompanied by changes in convergence measurements.

8/ Hudspeth, H. M., and Phillips, D. W., Forces Induced by the Extraction of Coal, and Some of Their Effects on Coal-Measure Strata: Trans. Inst. Min. Eng., vol. 85, 1933.

9/ Willett, H. L., Roof Control and Supports: Officials Handbook No. 2, Doncaster Amalgamated Collieries, Ltd., 1943.

10/ Henshaw, H., and Phillips, D. W., Underground and Surface Strata Movements: Trans. Inst. Min. Surveyors, vol. 22, 1942.

11/ Evans, W. H., Hogan, M. A., and Vallis, E. H., An Investigation of Loads on Packs at Moderate Depths: Trans. Inst. Min. Eng., vol. C., 1940-41

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Results illustrated in figure 3 were obtained by placing the measuring instruments in the middle of a 6-foot-high roadside pack near the center of a 210-yard face. Thickness of overburden was 1,050 feet; 57 percent of the mined-out area was packed. The load was 3,200 pounds per square inch when the coal face had advanced 234 feet from the instrument; 2,110 pounds at 310 feet; 3,300 pounds at 600 feet; and 3,200 pounds at approximately 670 feet, at which value it remained until the face had advanced 230 feet farther (to 900 feet). Although not shown in figure 3, the compression in the center of the pack was 32.6 percent at 200 feet, which approached the maximum recorded for this part of the pack; compression of the pack at the side reached 90 percent when the face had advanced 700 feet. Some of this is attributed to extrusion of the pack into the roadway, as shown by the curve for reduction in width of road in figure 3. Subsequent tests of this type on packs at another colliery failed to show the release and reapplication of pressure in the back abutment, which is evidenced in figure 3.12/

Effect of Quality of Packs on Mining Conditions

In figure 4 (A)2/, the span of the pressure arch supported at the front and back abutments, is much less than for the condition shown in figure 4 (B). Consequently, the strata loads on the abutments in figure 4 (A) are much less than in 4 (B), and face conditions are much better. To mine by caving under the strata loads associated with deep mining simply aggravates the conditions shown in figure 4 (B). Firm pack walls work to create the condition in figure 4 (A) and at the same time cause the wastes to cave without appreciable sagging. "Strip packing," as shown in figure 1, will give results as in figure 4 (A), if properly carried on, whereas "solid packing" could give results as shown in figure 4 (B), if packs are loosely built and waste rock is merely gobbed.

The effects of poor and good packs on roadway conditions are at once apparent from an examination of figure 5 (A) and (B)2/. The "double" or "cavity" packing system for roadway support, developed through research13/ and used with much success,14/15/16/ is illustrated in figure 6 (A) and (B)2/. With this system, the maximum roof loads are transmitted some distance each side of the roadway. This relieves the roadway itself of roof load and tendency for floor lift. The roadways shown in figure 6 (A) and (B) are similar to those illustrated in figure 1.

12/ Evans, W. H., and Jones, T. J., An Investigation of Loads on Packs at Moderate Depths. Part II: Trans., Inst. Min. Eng., vol. 105, 1945-46, pp. 286-302.

13/ Phillips, D. W., and Walker, L., Control of Longwall Roadways by Means of Packs: Trans., Inst. Min. Eng., vol. 96, 1938-39.

14/ Robinson, J. W., and Hodkin, C. H., Control of Longwall Roadways: Trans., Inst. Min. Eng., vol. 104, 1944-45.

15/ The Application of Double Packing on Longwall Roadways: Report of the Safety in Mines Research Committee of the North Staffordshire Institute of Mining Engineers.

16/ Scurfield, R. W., and Hodkin, C. H., Application of Double Packing at Littleton Colliery: Trans., Inst. Min. Eng., vol. 106, 1946.

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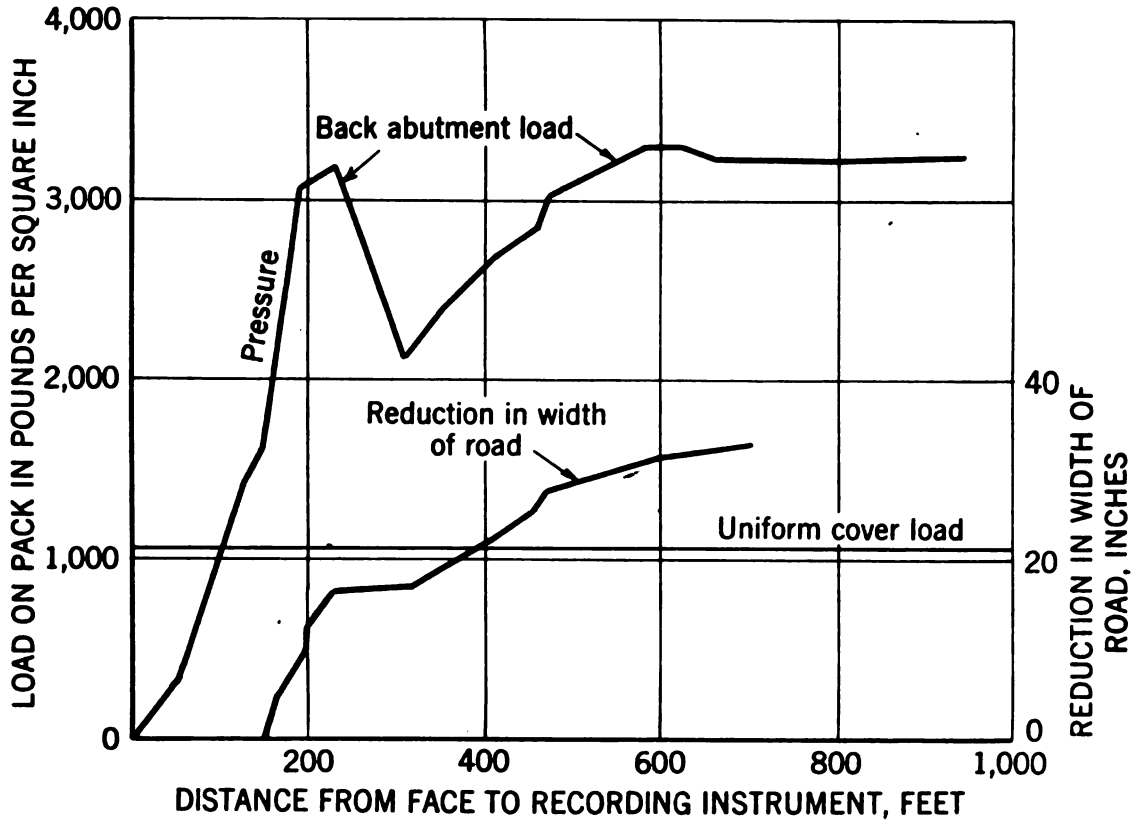

Figure 3. - Measured roof load on a roadway pack and reduction in width of roadway as the load increased.

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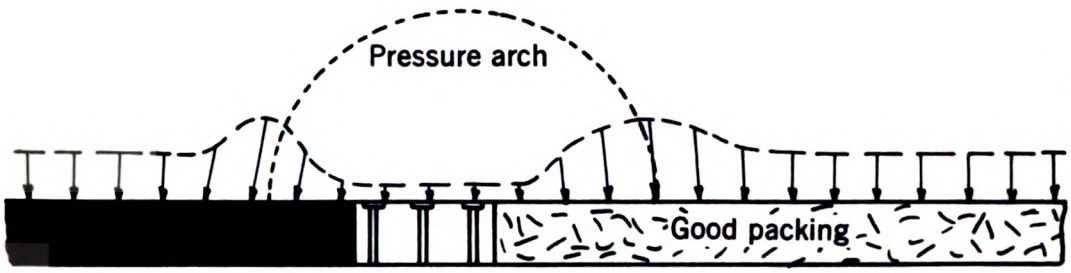
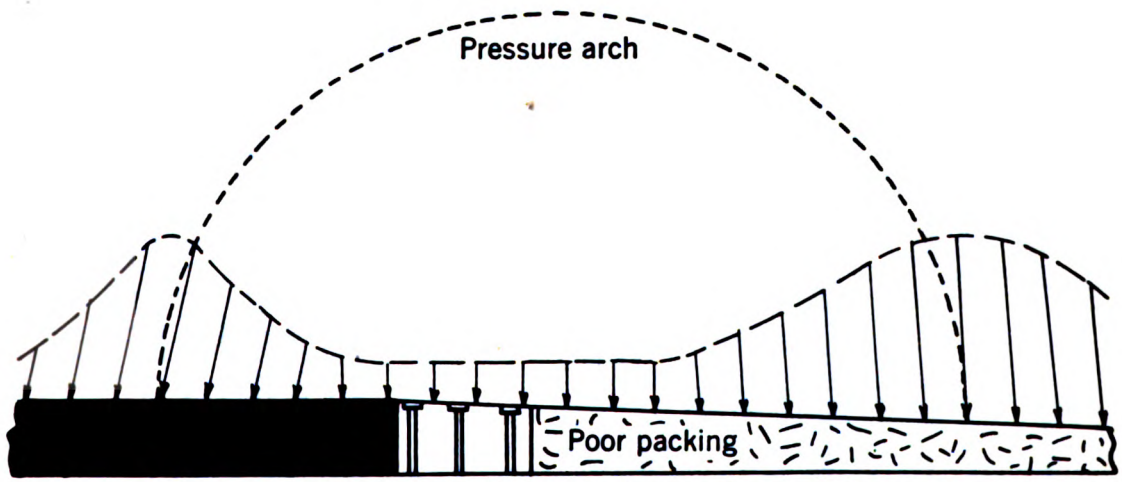


A-Narrow pressure arch, minimum load, good face conditions



B-Wide pressure arch, overload, poor face conditions

Figure 4. - Effect of quality of support on face conditions.

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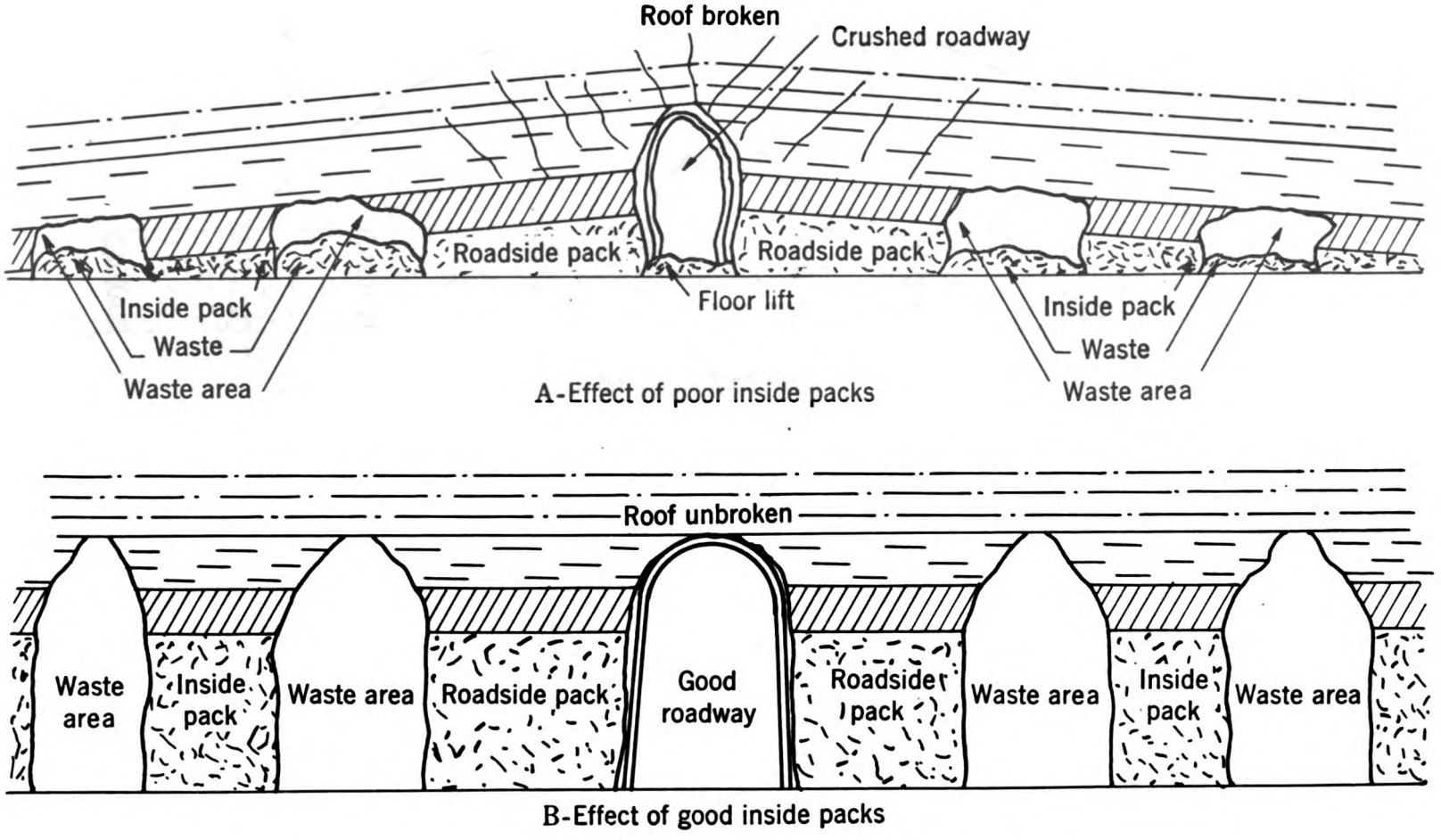

Figure 5: - Effect of quality of packing on roadway conditions.

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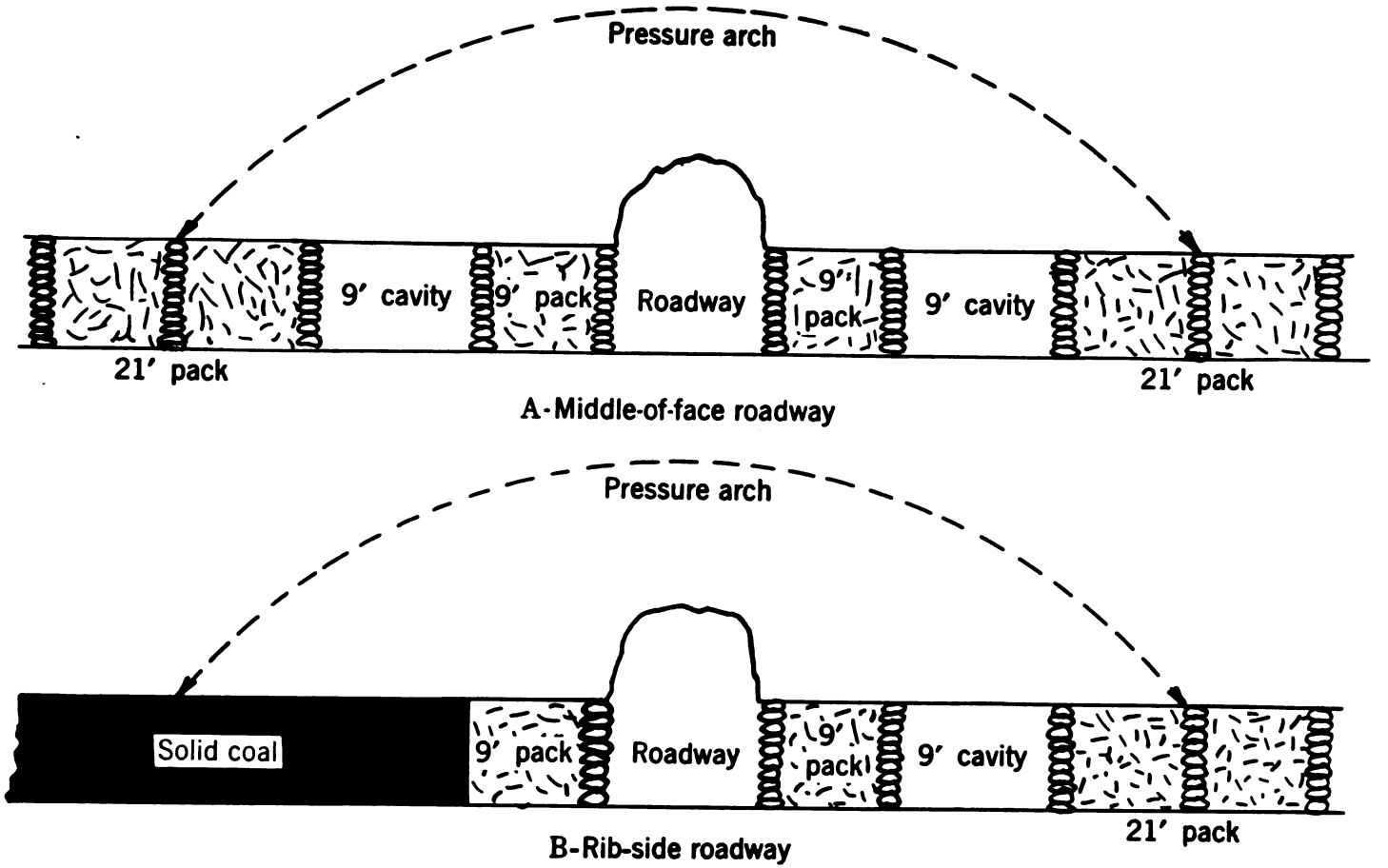

Figure 6. - Double or cavity packing.

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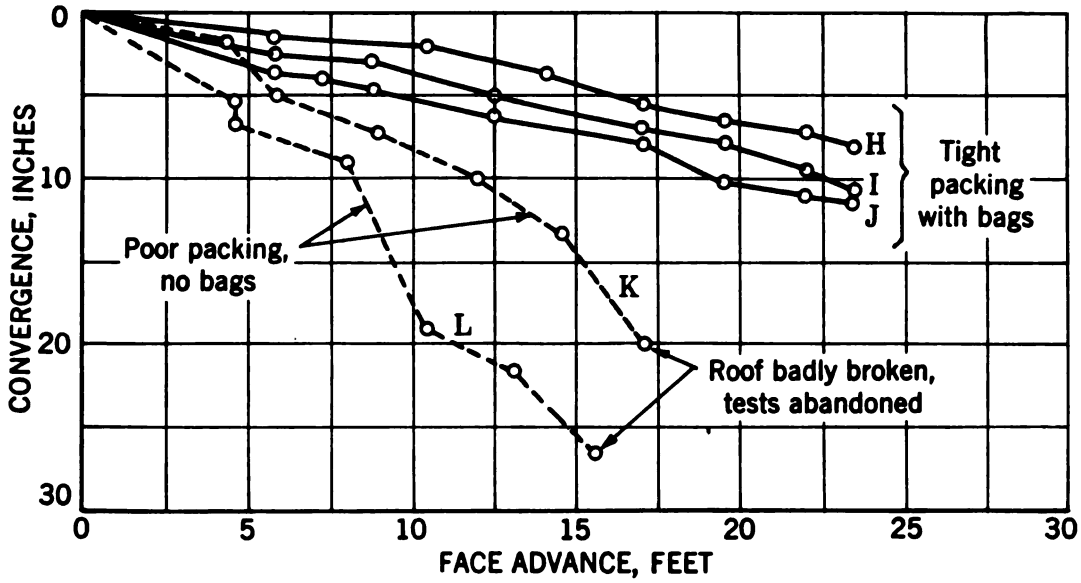

Figure 7. - Convergence tests. Sections of bed; at M, coal 6'6"; at I, coal 6'8½"; at J, coal 6'9"; at K, coal 7'2"; and at L, coal 6'4". Depth of bed 1,200 feet.

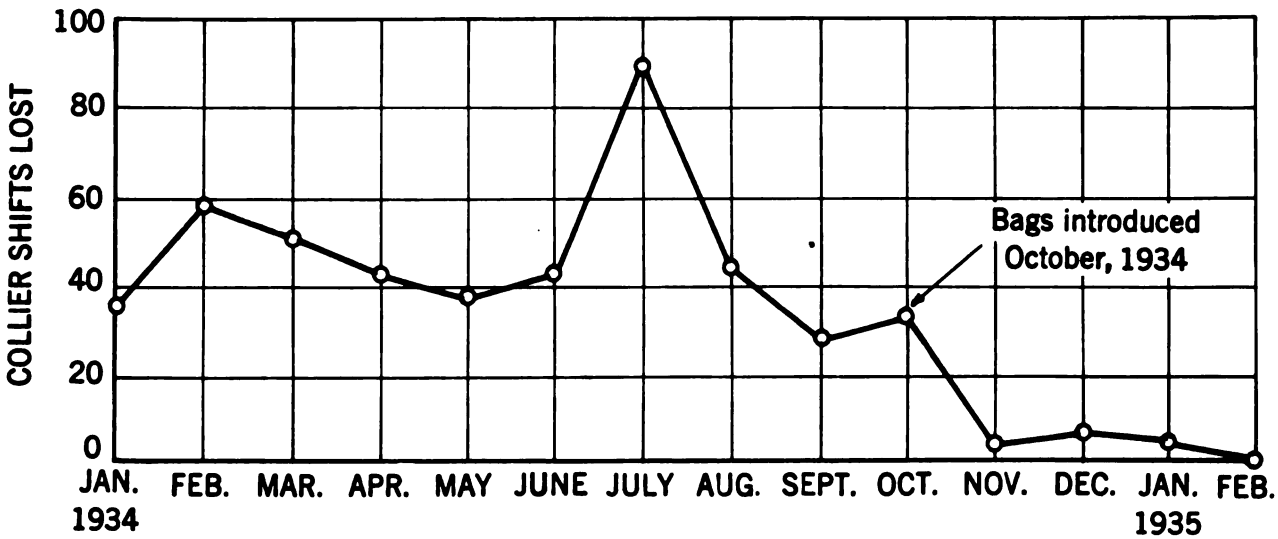

Figure 8. - Collier shifts lost owing to squeezes.

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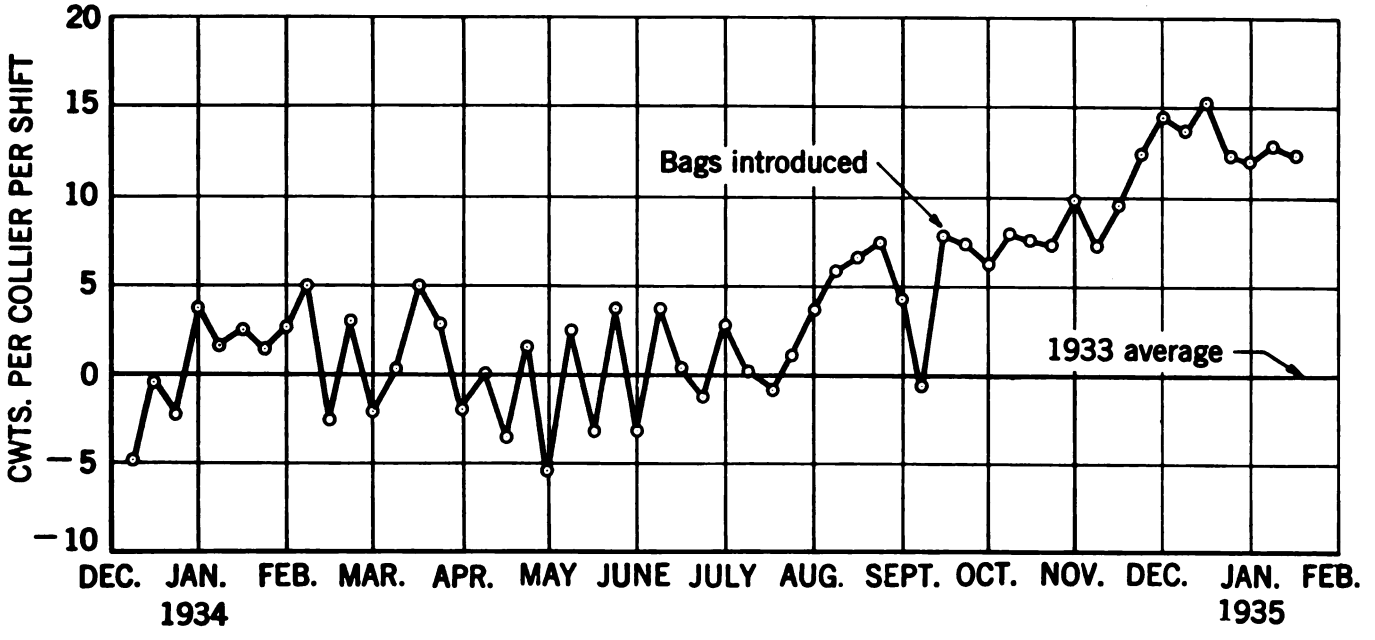

Figure 9. - Increase or decrease in cwt. per collier per shift compared with 1933 average.

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Bags have been used in South Wales to increase the stability of packs with highly favorable results.17/ Bags for fines are of cheap sacking material 33 inches long and 14 inches wide when empty; and 2-inch wire-mesh bags of approximately the same dimensions are used for coarse materials.18/ Some of the effects of better quality of packs when using bags are shown in figures 7, 8, and 9.19/ Obviously, mining conditions were much safer.

Cleavage Induced by Mining

Fracture cleavage is the term used by British mining engineers to designate cleavage lines induced in overlying strata by mining. These fractures are independent of any parallel arrangement of the mineral constituents of the rocks. Direction, inclination, effect of depth of beds, and nature of rocks in relation to cleavage have been carefully investigated.19/ The phenomenon is most common in shales and in sandstones occurs only at depths of more than 800 yards.

In comparatively weak strata, induced cleavage was not observed at depths less than 330 feet, but at depths of over 600 feet it was invariably present. In stronger strata the least depth at which it was found was 1,800 feet, at 1,890 feet in thin beds of sandstone, and consistently at 2,400 feet or more in strong, thick sandstones.

The general direction of the cleavage induced in longwall work is parallel to the face, curving to the rib at the side. Induced cleavage is found under conditions of constraint; if greater freedom were allowed, breaks would occur. The concentration of stresses produced by the weight of the overlying strata and the impingment of these stresses within the solid coal parallel to the face are the chief factors in producing induced cleavage. Quantitatively, induced cleavage is dependent on the speed of mining. The faster the mining, the less will be the induced cleavage, and conversely.

The direction of face advance with reference to cleat does not affect the cleavage. The weight of the overlying strata is the chief factor in inducing cleavage.19/

FACE AND ROADWAY SUPPORTS

Props

Steel pit props, both rigid and yielding, are used widely.20/ They are used with sills or caps and collars, as conditions require.

17/ Jeffreys, David, Underground Packing by Means of Bags: The South Wales Institute of Engineers, 1935.

18/ Hunter, J., Pneumatic Stowing at Bullcroft Main Colliery: Trans. Inst. Min. Eng., vol. 105, 1945.

19/ Faulkner, R., and Phillips, D. W., Cleavage Induced by Mining: Trans. Inst. Min. Eng., vol. 89, 1935.

20/ Ashley, T., Dixon, S. M., and Hogan, M. A., Steel Pit Props: Safety in Mines Research Board, Paper No. 58, 1930.

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Rigid props do not shorten appreciably, even under their maximum load. In the simplest form, a rigid prop consists of a single member, such as a tube (pipe), or joist (H beam), as shown in figure 10 (A).19/ For adjustments in roof and floor convergence, wooden cap pieces are usually used in conjunction with wooden props.

Yielding props shorten slowly and steadily when the load imposed upon them exceeds a definite value, whereas at the same time they offer either a constant or a gradually increasing resistance to roof pressure. Yielding props are more complicated in design than rigid props and frequently are built to provide for adjustable length and means to facilitate withdrawal. Many types have been described and tested. As an example, the yielding prop shown in figure 10 (B) will shorten 2 inches if a load of 10 tons is applied, 4 inches if the load is increased to 20 tons, and about 4-1/2 inches if the load is 22 tons. As the 4-1/2-inch shortening is the maximum length change possible in the prop head, it becomes, in effect, a rigid prop after a 22-ton load has been applied.20/ This is well within the range of the load which the prop is expected to carry.

Research has shown that consideration should be given to the type of bottom or floor before props are selected.21/ Where props are installed on a soft floor without provision for sufficient bearing area, the coal face becomes the pivot point for immediate roof beds resulting in greater abutment loads and poor face conditions.22/ A good prop should incorporate some method of yielding after proper resistance (which is determined by the distance between front and back abutments) is built up.

Some experimental work on the support of underground roof by bolting was conducted early in World War II.23/ Although results were encouraging, the work was limited to narrow openings and was restricted by wartime material shortages.

Arches

Two common types of yielding, steel, arched roadway supports are shown in figure 11 (A) and (B).9/ Rigid steel arches also are used, but the leg section is generally pitched outward at the bottom.

PNEUMATIC STOWING

A system of pneumatic stowing was initaited at one colliery to reduce the cost of building extremely tight, top-sealed, roadside packs, which were necessary to eliminate heatings.18/ In the 5 years 1935 to 1940, 93 heatings were treated. Two explosions occurred as a result of heatings, one in 1940 and one in 1941.

21/ Perrins, H. J., and Jenkins, J. R., A New Approach to Roof Control: The Colliery Guardian, Oct. 17, 1947, pp. 518-523.
Carter, W. H. N., and Evans, W. H. Measurement of Prop Resistance: Iron and Coal Trades Review, vol. CLIII, Aug. 2, 1946, pp. 181-185.

22/ Winstanley, A., Roof-Control Research and Practical Application: Trans., IME, vol. CIV, 1944-45, pp. 430-441.

23/ Beyl, Z. S., Rock Pressure and Roof Support: Colliery Engineering, Sept. 1943, pp. 206-208, 213; Oct. 1945, pp. 220-222, 228.

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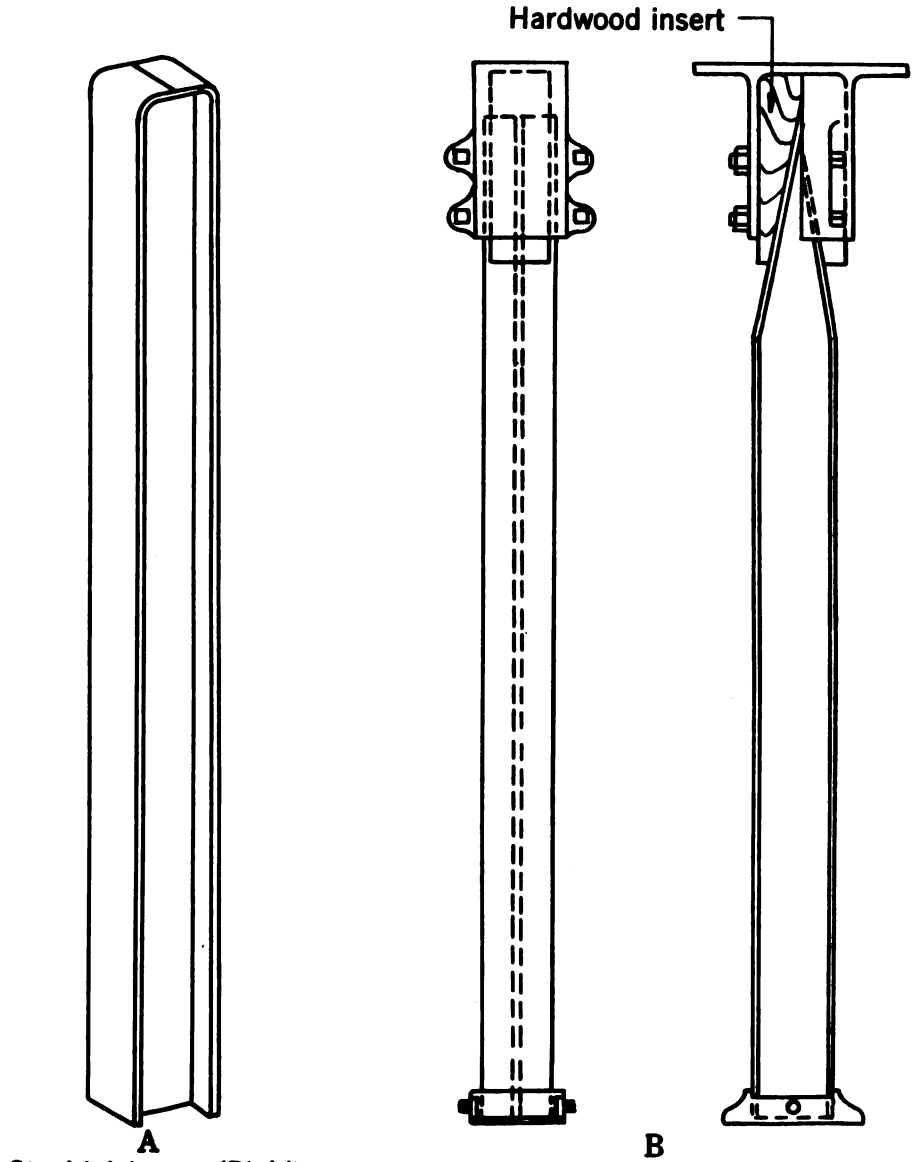

Figure 10. - Types of steel props.

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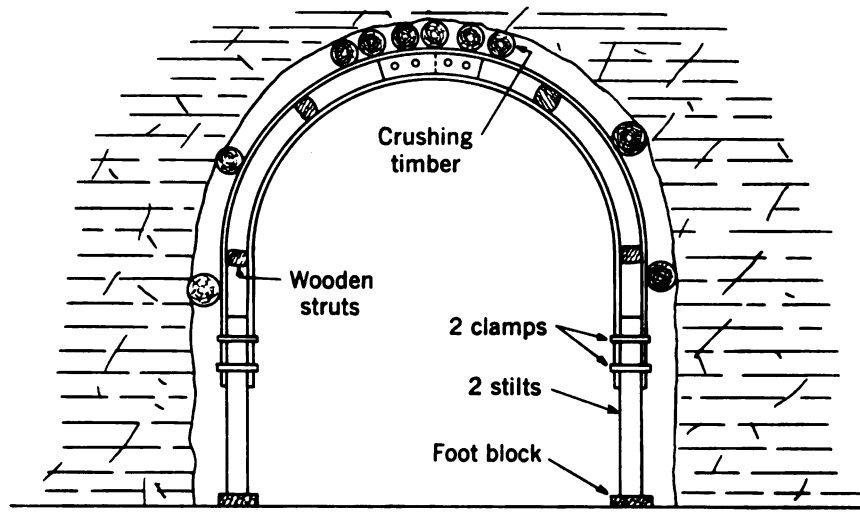
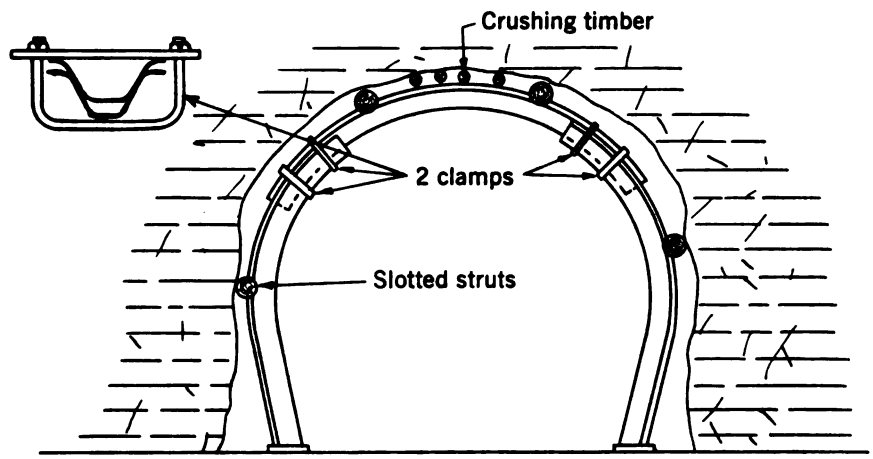


A-Arched girder on stilts



B-German arch

Figure 11. - Yielding type of roadway supports.

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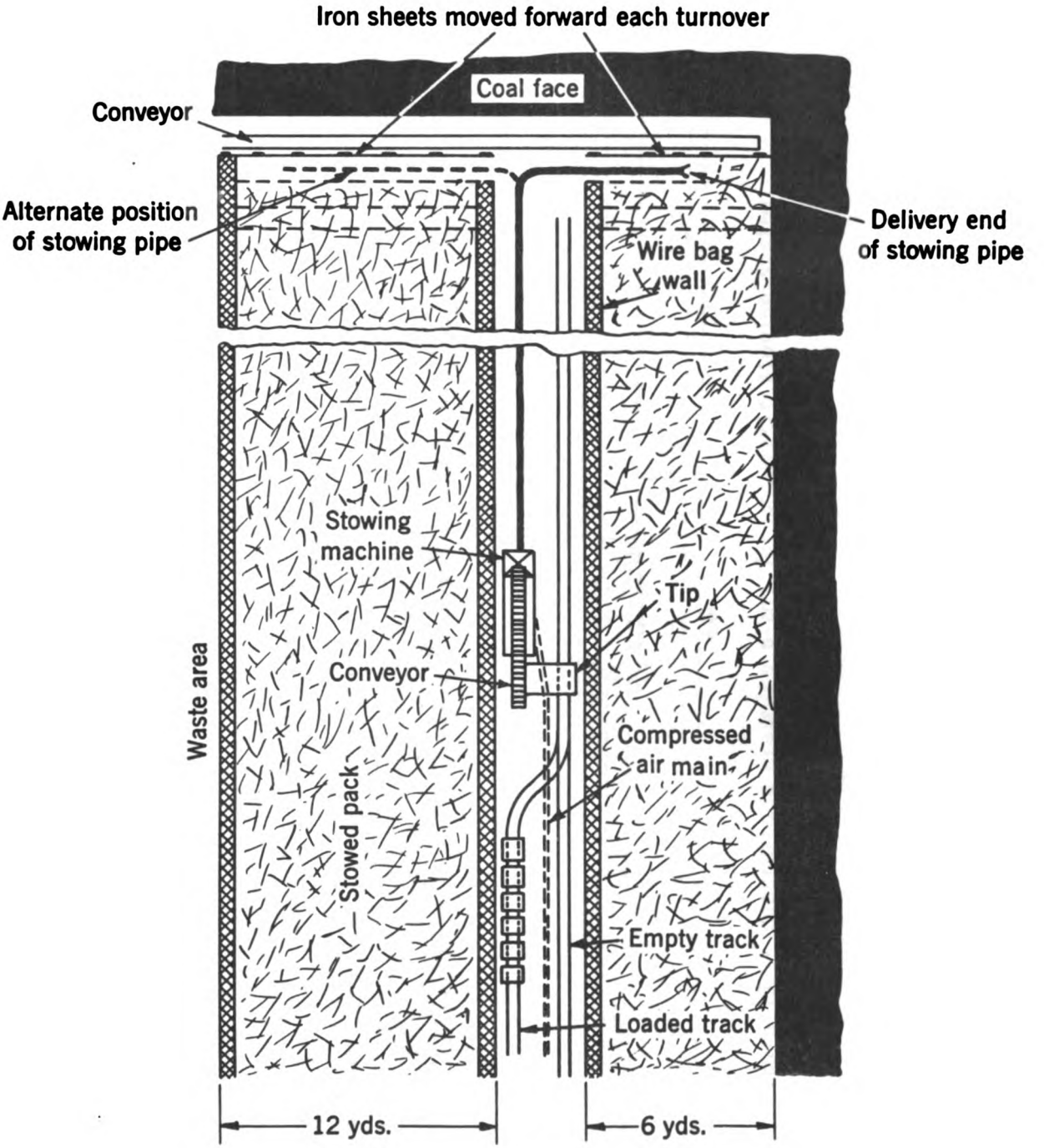

Figure 12. - Lay-out for pneumatic packing of rib-side roadways.

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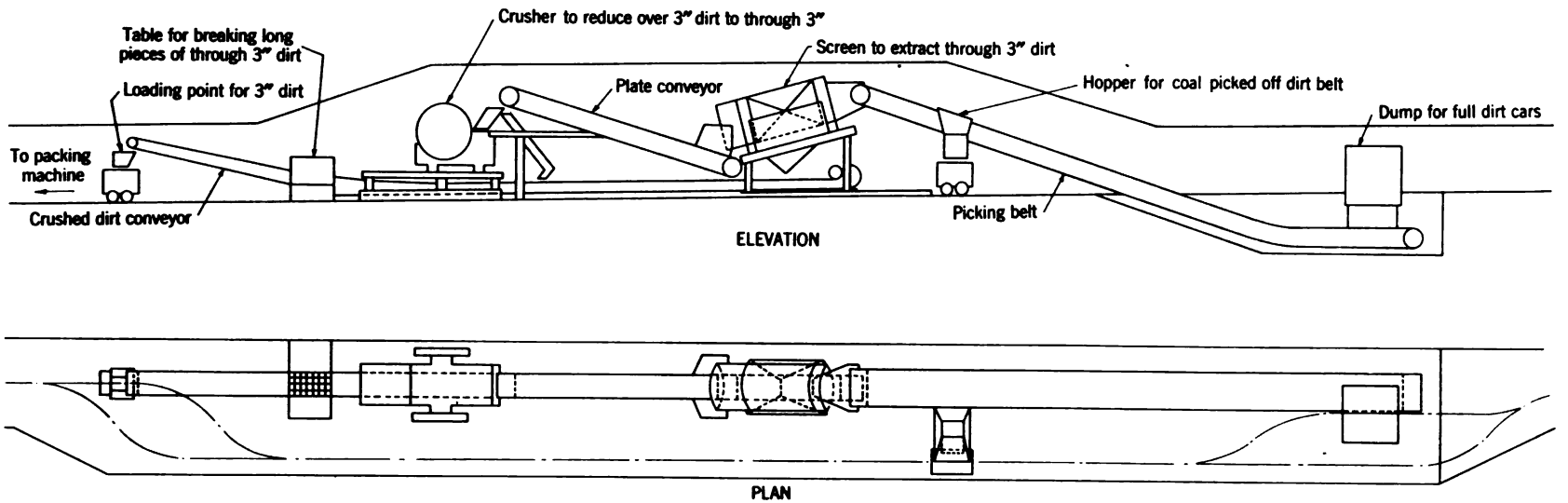
Table for breaking long pieces of through 3" dirt
Loading point for 3" dirt
To packing machine
Crushed dirt conveyor
Crusher to reduce over 3" dirt to through 3"
Plate conveyor
Screen to extract through 3" dirt
Hopper for coal picked off dirt belt
Dump for full dirt cars
Picking belt
ELEVATION
PLAN

Figure 13. - Underground crushing plant for pneumatic stowing system.

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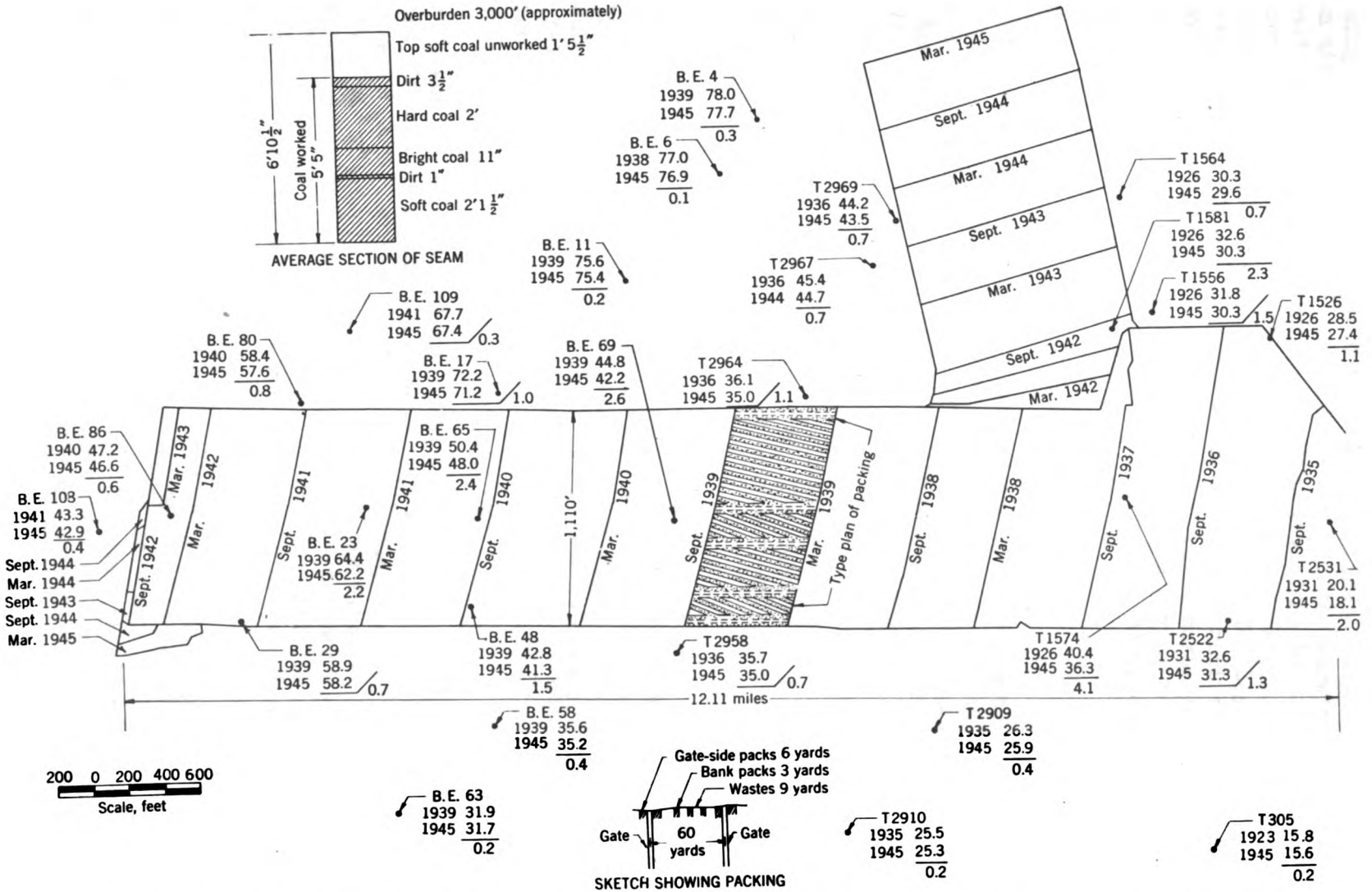

Figure 14. - Record of subsidence as of September 1945, Barnsley bed, Midland coal field, near Doncaster.

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The adoption of pneumatic stowing for rib-side packs proved so successful that it was extended to the construction of bank or gob packs in the strip-packing system. A face lay out is shown in figure 12.[18] Waste rock is fed from mine cars through the tip and conveyor to the stowing machine. It is forced from the machine through the discharge line by compressed air and is thrown forcefully into mined-out areas as shown. Pipe sections can be added or removed from the discharge line as required. The lay out of an underground rock-crushing plant for preparation of waste mine rock to minus 3-inch size is shown in figure 13.[18] Pneumatic stowing proved more economical than hand work and, for a single 150-yard face, resulted in a saving of approximately $7,000 per year, or 18 cents per ton, including capital cost, depreciation, replacements, compressed air, and labor charges.

SURFACE SUBSIDENCE

That the amount of surface subsidence is approximately even over a wide area is shown by the surface-subsidence data in figure 14, in which the extensive data have been summarized briefly. Observations were made every 6 months for the periods shown in the figure. With the single exception at station T1574, subsidence is about 2.5 feet over the workings after final settlement and 0.7 to 1.0 foot over the unmined areas adjacent to the workings. The bed mined is 5-1/2 feet thick, and the overburden is slightly more than 3,000 feet. Advancing longwall with strip packs, similar to the method shown in figure 1, was employed to mine the entire area. The surface is highly improved, and little, if any, damage to buildings or other surface construction or improvements has been reported.

Greater amounts of subsidence have been recorded. An investigation of subsidence data of one surface measuring point outside the area shown in figure 14, and well over the mine workings, showed a 4.1-foot subsidence over a period of 12 years in mining a 5-foot bed with a 2,700-foot overburden. This amount of subsidence represents 82 percent of the bed thickness. The pitch of the bed was 3-1/3 percent to the dip. The traveling draw was 360 yards, or about 83 degrees. Strip packing was used in mining the area.

CONCLUSIONS

It was the senior author's impression that the mining engineers of the United Kingdom have attacked the very difficult problem of mining thin coal beds, which lie deep (in one instance a 2-foot, 10-inch bed under 4,000 feet of cover was visited), safely and economically with the thoroughness and tenacity characteristic of their race. And they are not yet satisfied with the results obtained! The seventeen references to articles on roof control in this publication only begin to tap the vast wealth of research and operating data that has been published.

The true practical solution of roof-control problems that now prevail in the Pennsylvania anthracite region, and which will become increasingly important with future mining at greater depths, lies in a more technical and scientific approach than has been used generally. The past should not govern the future. Instruments must be provided and techniques developed for determining the forces that prevail, so that these forces may be controlled intelligently and economically. New methods of roof support, with materials not now in common use underground, should be studied with a view to providing, at minimum cost, the ultimate in safety from falls of roof at the working face, and at the same time providing for a continuous flow of coal from this same face.

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